EVALUATION KIT AVAILABLE

TC646

*Patent Granted

PWM Fan Speed Controller with Auto-Shutdown and FanSense™*

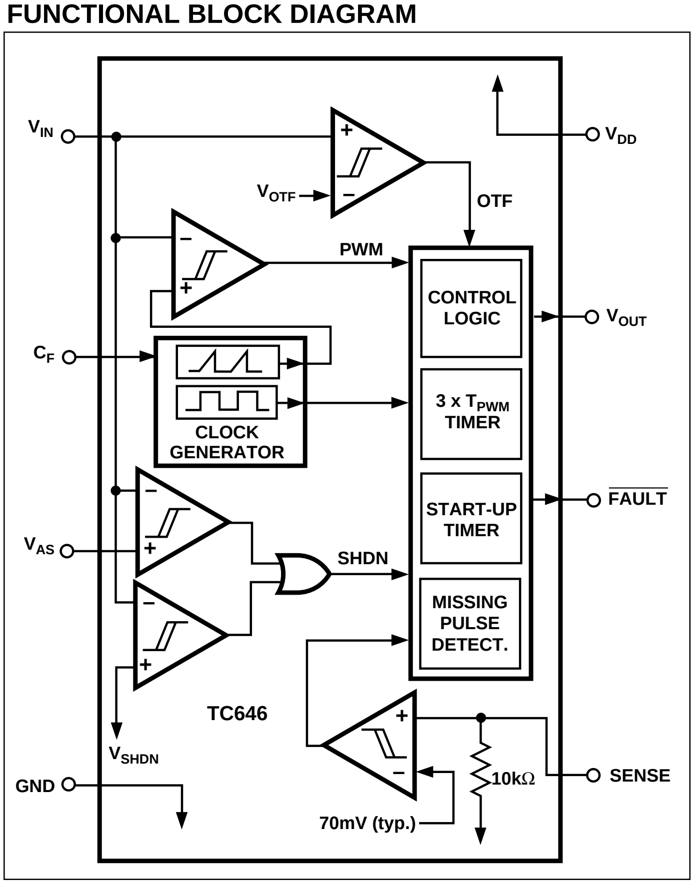
FEATURES

- **Temperature Proportional Fan Speed for Acoustic Control and Longer Fan Life**
- **Efficient PWM Fan Drive**
- **3.0V to 5.5V Supply Range; Fan Voltage Independent of TC646 Supply Voltage - Supports Any Fan Voltage!**
- **FanSense™ Fault Detection Circuits Protect Against Fan Failure and Aid System Testing**
- **Automatic Shutdown Mode for "Green" Systems**
- **Supports Low Cost NTC/PTC Thermistors**
- **Space-Saving 8-Pin PDIP and SOIC Packages**

APPLICATIONS

- **Power Supplies**
- **Computers**
- **Telecom Equipment**
- **Portable Computers**
- **UPS's, Power Amps, etc.**
- **General Purpose Fan Speed Control**

FUNCTIONAL BLOCK DIAGRAM



GENERAL DESCRIPTION

The TC646 is a switch mode fan speed controller for use with brushless DC motors. Temperature proportional speed control is accomplished using pulse width modulation (PWM). A thermistor (or other voltage output temperature sensor) connected to the V_{IN} input furnishes the required control voltage of 1.25V to 2.65V (typical) for 0% to 100% PWM duty cycle. The TC646 automatically suspends fan operation when measured temperature (V_{IN}) is below a user-programmed minimum setting (V_{AS}). An integrated Start-Up Timer ensures reliable motor start-up at turn-on, coming out of Shutdown mode, or following a transient fault.

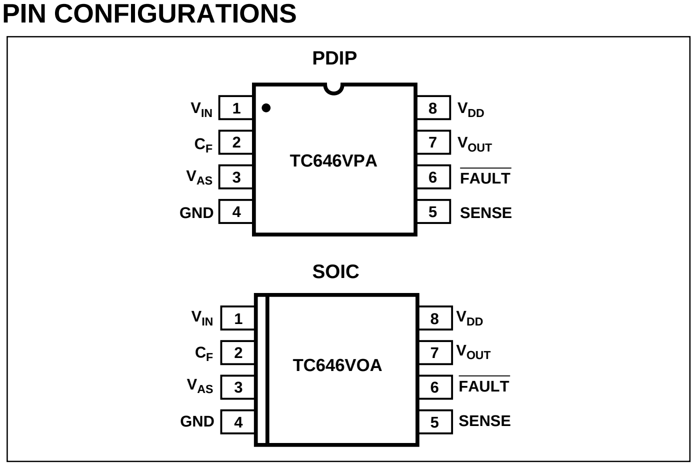
In normal fan operation, a pulse train is present at SENSE, pin 5. The TC646 also features Microchip Technology's proprietary FanSense™ technology for increasing system reliability. A missing-pulse detector monitors this pin during fan operation. A stalled, open, or unconnected fan causes the TC646 to trigger its startup timer once. If the fault persists, the $\overline{FAULT}$ output goes low, and the device is latched in its Shutdown Mode. $\overline{FAULT}$ is also asserted if the PWM reaches 100% duty cycle, indicating a possible thermal runaway situation, although the fan continues to run. See the **Applications** section for more information and system design guidelines.

The TC646 is packaged in a space-saving 8-pin plastic DIP or SOIC package and is available in the industrial temperature range.

ORDERING INFORMATION

Part No.	Package	Temp. Range
TC646VOA	8-Pin SOIC	0°C to +85°C
TC646VPA	8-Pin Plastic DIP	0°C to +85°C
TC642EV	***Evaluation Kit for TC646***	

PIN CONFIGURATIONS



ABSOLUTE MAXIMUM RATINGS*

Package Power Dissipation ($T_A \leq 70°C$)
- Plastic DIP 730mW
- Small Outline(SOIC) 470mW
- Micro SOP(MSOP) 333mW

Derating Factors .... 8mW/°C
Supply Voltage 6V
Input Voltage, Any Pin .... (GND – 0.3V) to (V_{CC} + 0.3V)
Maximum Chip Temperature .... +150°C
Storage Temperature Range .... – 65°C to +150°C
Lead Temperature (Soldering, 10 sec) .... +300°C

*Stresses above those listed under "Absolute Maximum Ratings" may cause permanent damage to the device. These are stress ratings only and functional operation of the device at these or any other conditions above those indicated in the operation sections of the specifications is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.

D.C. ELECTRICAL CHARACTERISTICS: $T_{MIN} \leq T_A \leq T_{MAX}$, V_{DD} = 3.0V to 5.5V, unless otherwise specified.

Symbol	Parameter	Test Conditions	Min	Typ	Max	Units
V_{DD}	Supply Voltage		3.0	—	5.5	V
I_{DD}	Supply Current, Operating	Pins 5, 7 Open, C_F = 1µF, $V_{IN} = V_{C(MAX)}$	—	0.5	1	mA
$I_{DD(SHDN)}$	Supply Current, Shutdown/ Auto-Shutdown Mode	Pins 5, 6, 7 Open; Note 1 C_F = 1µF, V_{IN} = 0.35V,	—	25	—	µA
I_{IN}	V_{IN}, V_{AS} Input Leakage	Note 1	– 1	—	+1	µA
V_{OUT} Output						
t_R	V_{OUT} Rise Time	I_{OH} = 5mA, Note 1	—	—	50	µsec
t_F	V_{OUT} Fall Time	I_{OL} = 1mA, Note 1	—	—	50	µsec
t_{RESET}	Pulse Width On V_{IN} to Enabled RESET	V_{SHDN}, V_{HYST} Specifications; Note 1	30	—	—	µsec
I_{OL}	Sink Current at V_{OUT} Output	V_{OL} = 10% of V_{DD}	1	—	—	mA
I_{OH}	Source Current at V_{OUT} Output	V_{OH} = 80% of V_{DD}	5	—	—	mA
Sense Input						
$V_{TH(SENSE)}$	SENSE Input Threshold Voltage With Respect to Ground	Note 1	50	70	90	mV
Fault Output						
V_{OL}	Output Low Voltage	I_{OL} = 2.5mA	—	—	0.3	V
t_{MP}	Missing Pulse Detector Time-out	C_F = 1.0µF	—	32/F	—	Sec
$t_{STARTUP}$	Start-up Time	C_F = 1.0µF	—	32/F	—	Sec
t_{DIAG}	Diagnostic Timer Period	C_F = 1.0µF	—	3/F	—	Sec

D.C. ELECTRICAL CHARACTERISTICS (Cont.): $T_{MIN} \le T_A \le T_{MAX}$, V_{DD} = 3.0V to 5.5V unless otherwise specified.

Symbol	Parameter	Test Conditions	Min	Typ	Max	Units
V_{IN}, V_{AS} Inputs						
$V_{C(MAX)}$, V_{OTF}	Voltage at V_{IN} for 100% Duty Cycle and Overtemp. Fault		2.5	2.65	2.8	V
$V_{C(SPAN)}$	$V_{C(MAX)} – V_{C(MIN)}$		1.3	1.4	1.5	V
V_{AS}	Auto-Shutdown Threshold		$V_{C(MAX)} – V_{C(SPAN)}$	—	$V_{C(MAX)}$	V
V_{SHDN}	Voltage on V_{IN} to Activate RESET/SHUTDOWN		—	—	V_{DD} x 0.13	V
V_{REL}	Voltage Applied to V_{IN} to Release Reset Mode	V_{DD} = 5V (Refer to Figure 13)	V_{DD} x 0.19	—	—	V
V_{HYST}	Hysteresis on V_{SHDN}, V_{REL}		—	0.01 x V_{DD}	—	V
V_{HAS}	Hysteresis on Auto-Shutdown Comparator		—	70	—	mV
Pulse-Width Modulator						
F_{OSC}	PWM Frequency	C_F = 1.0µF	26	30	34	Hz

NOTE: 1. Ensured by design, not tested.

PIN DESCRIPTION

Pin No. (PDIP/SOIC)	Symbol	Description
1	V_{IN}	Analog input. The thermistor network (or other temperature sensor) connects to this input. A voltage range of 1.25V to 2.65V (typical) on this pin drives an active duty cycle of 0% to 100% on the V_{OUT} pin. The TC646 enters Shutdown mode when $0 \le V_{IN} \le V_{SHDN}$. During Shutdown, the $\overline{FAULT}$ output is inactive, and supply current falls to 25µA (typical). The TC646 exits Shutdown mode when $V_{IN} \ge V_{REL}$. See *Applications* section for more details.
2	C_F	Analog output. Positive terminal for the PWM ramp generator timing capacitor. The recommended C_F is 1µF for 30Hz PWM operation.
3	V_{AS}	Analog input. An external resistor divider connected to this input sets the Auto-Shutdown threshold. Auto-shutdown occurs when $V_{IN} \le V_{AS}$. The fan is automatically restarted when $V_{IN} \ge (V_{AS} + V_{HAS})$. See the *Applications* section for more details.
4	GND	Ground Terminal.
5	SENSE	Analog input. Pulses are detected at this pin as fan rotation chops the current through the sense resistor, R_{SENSE}. The absence of pulses indicates a fault(FanSense™). See the *Applications* section for more details.
6	$\overline{FAULT}$	Digital (open collector) output. This line goes low to indicate a fault condition. When $\overline{FAULT}$ goes low due to a fan fault, the device is latched in Shutdown mode until deliberately cleared, or until power is cycled. When $\overline{FAULT}$ goes low due to an over-temperature condition (OTF), the fan continues to run.
7	V_{OUT}	Digital output. This active high complementary output drives the base of an external NPN transistor via an appropriate base resistor. This output has asymmetrical drive. See *Electrical Characteristics* section.
8	V_{DD}	Power supply input. May be independent of fan power supply. See *Electrical Characteristics* section.

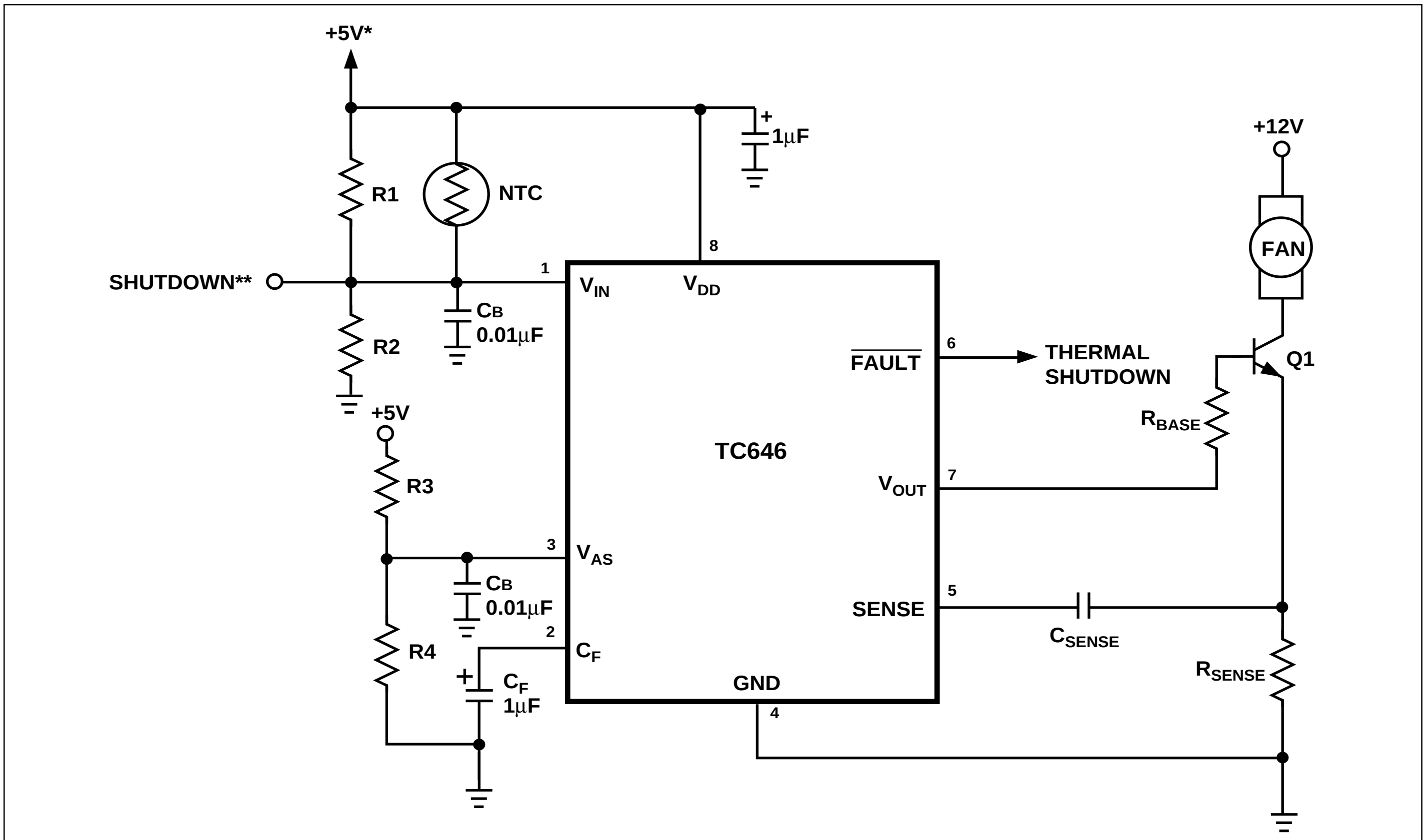


Figure 1. Typical Application Circuit

DETAILED DESCRIPTION

PWM

The PWM circuit consists of a ramp generator and threshold detector. The frequency of the PWM is determined by the value of the capacitor connected to the C_F pin. A frequency of 30Hz is recommended for most applications ($C_F = 1.0\mu F$). The PWM is also the timebase for the Start-up and Fault Timer (see paragraphs below). The PWM voltage control range is 1.25V to 2.65V (typical) for 0% to 100% output duty cycle.

V_{OUT} Output

The V_{OUT} pin is designed to drive a low-cost transistor or MOSFET as the low side power switching element in the system. Various examples of driver circuits will be shown below. This output has an asymmetric complementary drive and is optimized for driving NPN-transistors or N-channel MOSFETs. Since the system relies on PWM rather than linear power control, the dissipation in the power switch is kept to a minimum. Generally, very small devices (TO-92 or SOT packages) will suffice.

Start-Up Timer

To ensure reliable fan start-up, the Start-up Timer turns the V_{OUT} output on for 32 cycles of the PWM whenever the fan is started from the off state. This occurs at power-up and when coming out of Shutdown or Auto-Shutdown modes. If the PWM frequency is 30Hz ($C_F = 1\mu F$) the resulting start-up time will be about one second. If a fan fault is detected (see below), the Diagnostic Timer is triggered once followed by the Startup Timer. If the fault persists, the device is shutdown. See $\overline{\text{FAULT}}$ Output below.

SENSE Input (FanSense™)

The SENSE input, pin 5, is connected to a low-value current sensing resistor in the ground return leg of the fan circuit. During normal fan operation, commutation occurs as each pole of the fan is energized. This causes brief interruptions in the fan current, seen as pulses across the sense resistor. If the device is not in Shutdown or Auto-Shutdown modes, and pulses are not appearing at the SENSE input, a fault exists.

The short, rapid change in fan current (high dI/dt) causes a corresponding dV/dt across the sense resistor, R_{SENSE}. The waveform on R_{SENSE} is differentiated and converted to a logic-level pulse-train by C_{SENSE} and the internal signal processing circuitry. The presence and frequency of this pulse-train is a direct indication of fan operation. See the Applications section for more details.

$\overline{FAULT}$ Output

The TC646 detects faults in two ways: (1) Pulses appearing at SENSE due to the PWM turning on are blanked, and the remaining pulses are filtered by a missing pulse detector. If consecutive pulses are not detected for thirty-two PWM cycles (≈1 Sec if C_F = 1µF), the Diagnostic Timer is activated, and V_{OUT} is driven continuously for three PWM cycles (≈100msec if C_F = 1µF). If a pulse is not detected within this window, the Start-up Timer is triggered (see Start-up Timer section). This should clear a transient fault condition. If the Missing Pulse Detector times out again, the PWM is stopped, and $\overline{FAULT}$ goes low. When $\overline{FAULT}$ is activated due to this condition, the device is latched in Shutdown Mode and will remain off indefinitely. The TC646 is thus prevented from attempting to drive a fan under catastrophic fault conditions.

One of two things will restore operation: Cycling power off and then on again; or pulling V_{IN} below V_{SHDN} and releasing it to a level above V_{REL}. When one of these two conditions is satisfied, the normal startup cycle is triggered, and operation will resume if the fault has been cleared.

(2) $\overline{FAULT}$ is also asserted when the PWM control voltage applied to V_{IN} becomes greater than that needed to drive 100% duty cycle (see *Electrical Characteristics*). This indicates that the fan is at maximum drive, and the potential exists for system overheating. Either heat dissipation in the system has gone beyond the cooling system's design limits, or some subtle fault exists such as fan bearing failure or an airflow obstruction. This output may be treated as a "System Overheat" warning and used to trigger system shutdown or some other corrective action.

However, in this case, the fan will continue to run even when $\overline{FAULT}$ is asserted. If the system is allowed to continue operation and the temperature (and thus V_{IN}) falls, the $\overline{FAULT}$ output will become inactive when $V_{IN} < V_{OTF}$.

Auto-Shutdown Mode

If the voltage on V_{IN} becomes less than the voltage on V_{AS}, the fan is automatically shut off (Auto-Shutdown mode). The TC646 exits Auto-Shutdown mode when the voltage on V_{IN} becomes higher than the voltage on V_{AS} by V_{HAS}, the Auto-Shutdown Hysteresis Voltage (see Figure 10). The Start-up Timer is triggered, and normal operation is resumed on exiting Auto-Shutdown mode. The $\overline{FAULT}$ output is unconditionally inactive in Auto-Shutdown mode.

Shutdown Mode (Reset)

If an unconditional shutdown and/or device reset is desired, the TC646 may be placed in Shutdown mode by forcing V_{IN} to a logic low, i.e., $V_{IN} < V_{SHDN}$ (see Figure 10). In this mode, all functions cease, and the $\overline{FAULT}$ output is unconditionally inactive. The fan will remain off regardless of the voltage on V_{IN}. The TC646 should not be shut down unless all heat producing activity in the system is at a negligible level. The TC646 exits Shutdown mode when V_{IN} becomes greater than V_{REL}, the Release Voltage. (Assuming $V_{IN} > V_{AS} + V_{HAS}$).

Entering Shutdown mode also performs a complete device reset. Shutdown mode resets the TC646 into its power-up state. The start-up and fault timers are cleared, and any current faults are cleared. $\overline{FAULT}$ is unconditionally inactive in Shutdown mode. Upon exiting Shutdown mode ($V_{IN} > V_{REL}$), the Start-up Timer will be triggered, and normal operation will resume, assuming no fault conditions exist. Note: if $V_{IN} < V_{AS}$ when the device exits Shutdown mode, the fan will not restart, but will be in Auto-Shutdown mode.

If a Fan Fault has occurred and the device has latched itself into Shutdown mode, performing a reset will not clear the fault unless $V_{IN} > (V_{AS} + V_{HAS})$. If V_{IN} is not greater than $(V_{AS} + V_{HAS})$ upon exiting Shutdown mode, the fan will not be restarted, and, therefore, there is no way to establish that the Fan Fault has been cleared. To ensure that a complete Reset takes place, the user's circuitry must ensure that $V_{IN} > (V_{AS} + V_{HAS})$ when the device is released from Shutdown mode. A recommended algorithm for management of the TC646 by a host microcontroller or other external circuitry is given in the applications section.

A small amount of hysteresis, typically one percent of V_{DD}, (50mV at V_{DD} = 5.0V) is designed into the V_{SHDN}/V_{REL} threshold. The levels specified for V_{SHDN} and V_{REL} in the *Electrical Characteristics* section include this hysteresis plus adequate margin to account for normal variations in the absolute value of the threshold and hysteresis.

CAUTION: Shutdown mode is unconditional. That is, the fan will remain off regardless of system temperature, i.e., the voltage on V_{IN}.

SYSTEM BEHAVIOR

The flowcharts describing the TC646's behavioral algorithm are shown in Figure 2. They can be summarized as follows:

Power-Up

(1) Assuming the device is not being held in Shutdown mode ($V_{IN} > V_{AS}$);

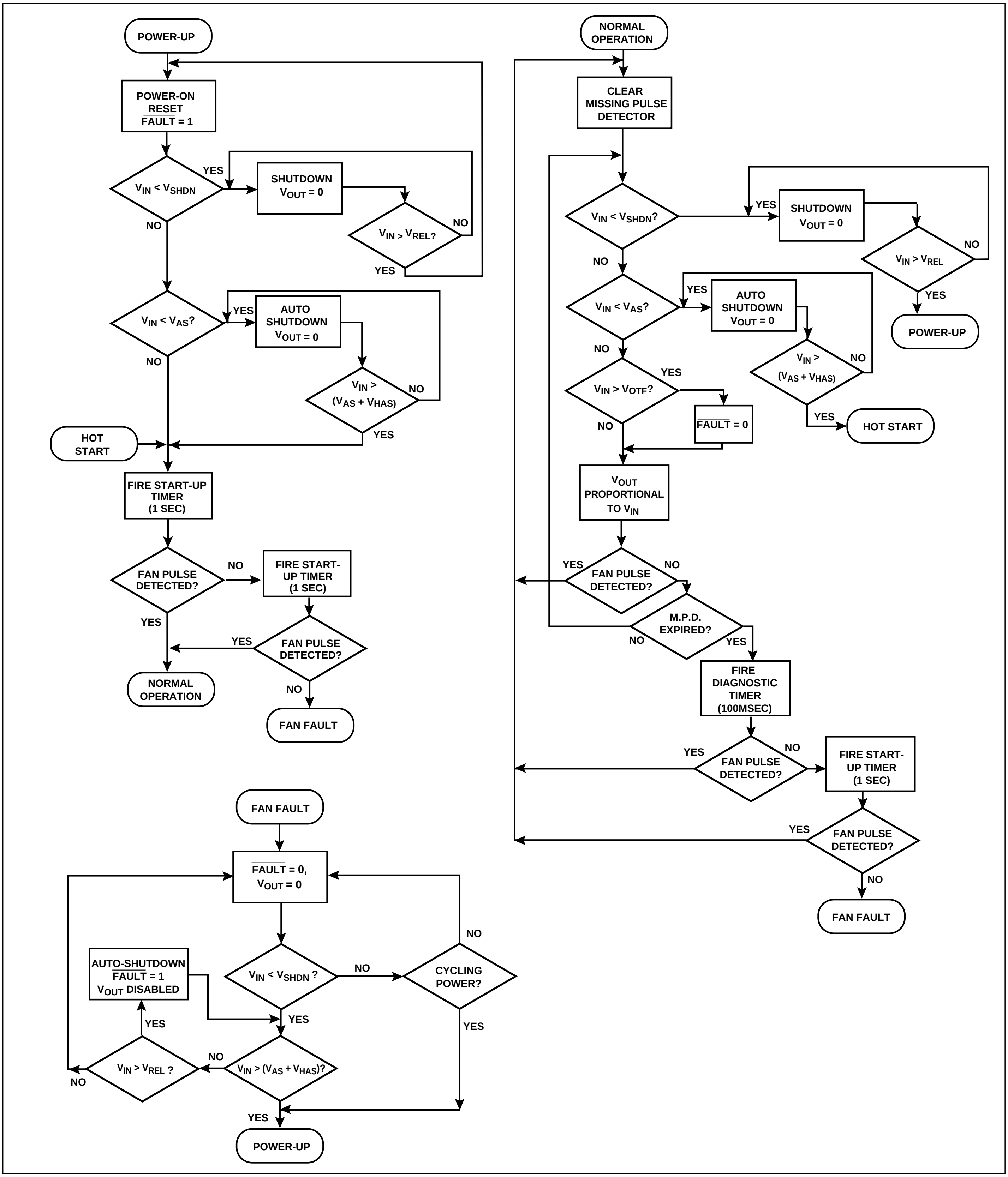


Figure 2. TC646 Behavioral Algorithm Flowcharts

(2) Turn V_{OUT} output on for 32 cycles of the PWM clock. This ensures that the fan will start from a dead stop.

(3) During this Startup Timer, if a fan pulse is detected, branch to Normal Operation; if none are received...

(4) Activate the 32-cycle Startup Timer one more time and look for fan pulse. If a fan pulse is detected, proceed to Normal Operation. If none are received...

(5) Proceed to Fan Fault.

(6) End.

Normal Operation

Normal Operation is an endless loop which may only be exited by entering Shutdown mode or Fan Fault. The loop can be thought of as executing at the frequency of the oscillator and PWM.

(1) Reset the Missing Pulse Detector.

(2) Is the TC646 in Shutdown? If so…

a. V_{OUT} duty-cycle goes to zero.

b. $\overline{FAULT}$ is not activated.

c. Exit the loop and wait for $V_{IN} > (V_{AS} + V_{HAS})$ to resume operation.

(3) If an over-temperature fault occurs ($V_{IN} > V_{OTF}$) then activate $\overline{FAULT}$; Release $\overline{FAULT}$ when $V_{IN} < V_{OTF}$.

(4) Drive V_{OUT} to a duty-cycle proportional to V_{IN} on a cycle by cycle basis.

(5) If a fan pulse is detected, branch back to the start of the loop (1).

(6) If the missing pulse detector times out…

(7) Activate the 3-cycle Diagnostic Timer and look for pulses. If a fan pulse is detected, branch back to the start of the loop (1). If none are received…

(8) Activate the 32-cycle Startup Timer and look for pulses. If a fan pulse is detected, branch back to the start of the loop (1). If none are received…

(9) Quit Normal Operation and go to Fan Fault.

(10) End.

Fan Fault

Fan Fault is essentially an infinite loop wherein the TC646 is latched in Shutdown mode. This mode can only be released by a Reset, i.e., V_{IN} being brought below V_{SHDN} and then above ($V_{AS} + V_{HAS}$) or by power-cycling.

(1) While in this state, $\overline{FAULT}$ is latched on (low), and the V_{OUT} output is disabled.

(2) A Reset sequence applied to the V_{IN} pin will exit the loop to Power-Up.

(3) End.

APPLICATIONS INFORMATION

Designing with the TC646 involves the following:

(1) The temperature sensor network must be configured to deliver 1.25V to 2.65V on V_{IN} for 0% to 100% of the temperature range to be regulated.

(2) The Auto-Shutdown temperature must be set with a voltage divider on V_{AS}.

(3) The output drive transistor and associated circuitry must be selected.

(4) The Sense Network, R_{SENSE} and C_{SENSE}, must be designed for maximum efficiency while delivering adequate signal amplitude.

(5) If Shutdown capability is desired, the drive requirements of the external signal or circuit must be considered.

The TC642DEMO demonstration and prototyping board and the TC642EV Evaluation Kit provide working examples of TC646 circuits and prototyping aids. The TC642DEMO is a printed circuit board optimized for small size and ease of inclusion into system prototypes. The TC642EV is a larger board intended for benchtop development and analysis. At the very least, anyone contemplating a design using the TC646 should consult the documentation for both the TC642EV and TC642DEMO.

Temperature Sensor Design

The temperature signal connected to V_{IN} must output a voltage in the range of 1.25V to 2.65V (typical) for 0% to 100% of the temperature range of interest. The circuit of Figure 3 is a convenient way to provide this signal.

Figure 3 illustrates a simple temperature-dependent voltage divider circuit. T_1 is a conventional NTC thermistor while R1 and R2 are standard resistors. The supply voltage, V_{DD}, is divided between R2 and the parallel combination of T_1 and R1. For convenience, the parallel combination of

T_1 and R1 will be referred to as R_{TEMP}. The resistance of the thermistor at various temperatures is obtained from the manufacturer's specifications. Thermistors are often referred to in terms of their resistance at 25°C. A thermistor with a 25°C resistance on the order of 100kΩ will result in reasonable values for R1, R2, and I_{DIV}. In order to determine R1 and R2, we must specify the fan duty-cycle, i.e. V_{IN} at any two temperatures. Equipped with these two points on the system's operating curve and the thermistor data, we can write the defining equations:

$$\frac{V_{DD} \text{ x } R2}{R_{TEMP}(t_1) + R2} = V(t_1)$$

$$\frac{V_{DD} \text{ x } R2}{R_{TEMP}(t_2) + R2} = V(t_2)$$

Equation 1.

Where t_1 and t_2 are the chosen temperatures, and R_{TEMP} is the parallel combination of the thermistor and R1. These two equations permit solving for the two unknown variables, R1 and R2. Note that resistor R1 is not absolutely necessary, but it helps to linearize the response of the network.

Auto-Shutdown Temperature Design

A voltage divider on V_{AS} sets the temperature where the part is automatically shut down if the sensed temperature at V_{IN} drops below the set temperature at V_{AS} (i.e. $V_{IN} < V_{AS}$).

As with the V_{IN} inputs, 1.25V to 2.65V corresponds to the temperature range of interest from t_1 to t_2, respectively. Assuming that the temperature sensor network designed above is linearly related to temperature, the shutdown temperature t_{AS} is related to t_2 and t_1 by:

$$\frac{2.65V - 1.25V}{t_2 - t_1} = \frac{V_{AS} - 1.25}{t_{AS} - t_1}$$

$$V_{AS} = \left(\frac{1.4V}{t_2 - t_1}\right)(t_{AS} - t_1) + 1.25$$

Equation 2.

For example, if 1.25V and 2.65V at V_{IN} corresponds to a temperature range of t_1 = 0°C to t_2 = 125°C, and the auto-shutdown temperature desired is 25°C, then V_{AS} voltage is:

$$V_{AS} = \frac{1.4V}{(125 - 0)}(25 - 0) + 1.25 = 1.53V$$

Equation 3.

The V_{AS} voltage may be set using a simple resistor divider as shown in Figure 4. Per the *Electrical Characteristics*, the leakage current at the V_{AS} pin is no more than 1µA. It is conservative to design for a divider current, I_{DIV}, of 100µA. If V_{DD} = 5.0V then…

$$I_{DIV} = 1e^{-4} A = \frac{5.0V}{R1 + R2}, \text{ therefore}$$

$$R1 + R2 = \frac{5.0V}{1e^{-4} A} = 50{,}000\Omega = 50k\Omega$$

Equation 4.

We can further specify R1 and R2 by the condition that the divider voltage is equal to our desired V_{AS}. This yields the equation:

$$V_{AS} = V_{DD} \text{ x } \frac{R2}{R1 + R2}$$

Equation 5.

Solving for the relationship between R1 and R2 results in:

$$R1 = R2 \text{ x } \frac{V_{DD} - V_{AS}}{V_{AS}} = R2 \text{ x } \frac{5 - 1.53}{1.53}$$

Equation 6.

In the case of this example, R1 = (2.27) R2. Substituting this relationship back into Equation 4 yields the resistor values:

R2 = 15.3kΩ, and
R1 = 34.7kΩ

In this case, the standard values of 35kΩ and 15kΩ are very close to the calculated values and would be more than adequate.

Operations at Low Duty Cycle

One boundary condition which may impact the selection of the minimum fan speed is the irregular activation of the Diagnostic Timer due to the TC646 "missing" fan commutation pulses at low speeds. Typically, this only occurs at very low duty-cycles (25% or less). It is a natural consequence of low PWM duty-cycles. Recall that the SENSE function detects commutation of the fan as disturbances in the current through R_{SENSE}. These can only occur when the fan is energized, i.e., V_{OUT} is "on". At very low duty-cycles the V_{OUT} output is "off" most of the time. The fan may be rotating normally, but the commutation events are occurring during the PWM's off-time.

The phase relationship between the fan's commutation and the PWM edges tends to "walk around" as the system

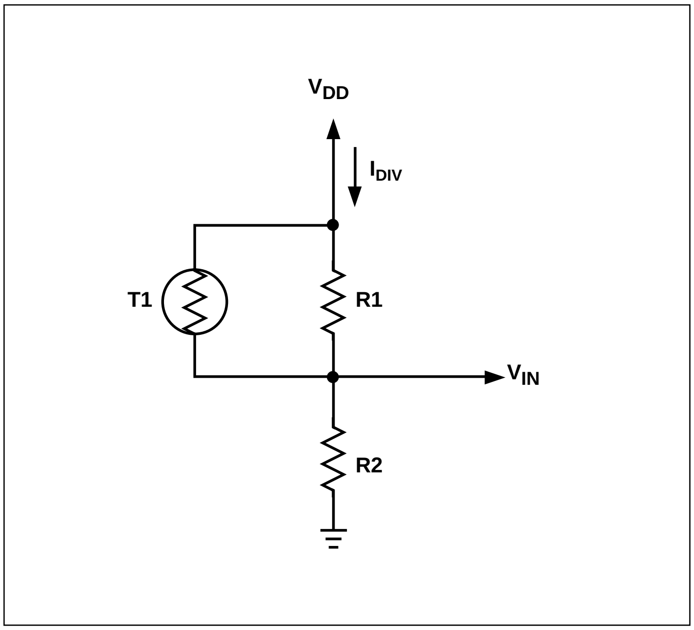


Figure 3. Temperature Sensing Circuit

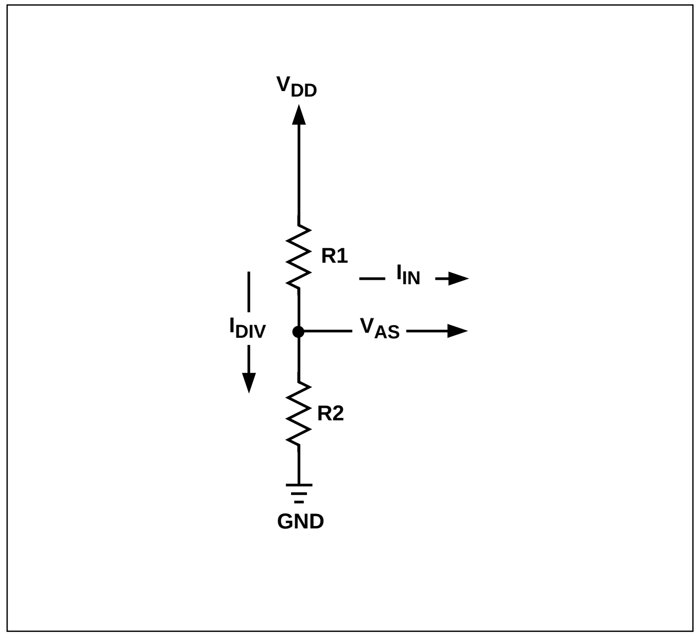


Figure 4. V_{AS} Circuit

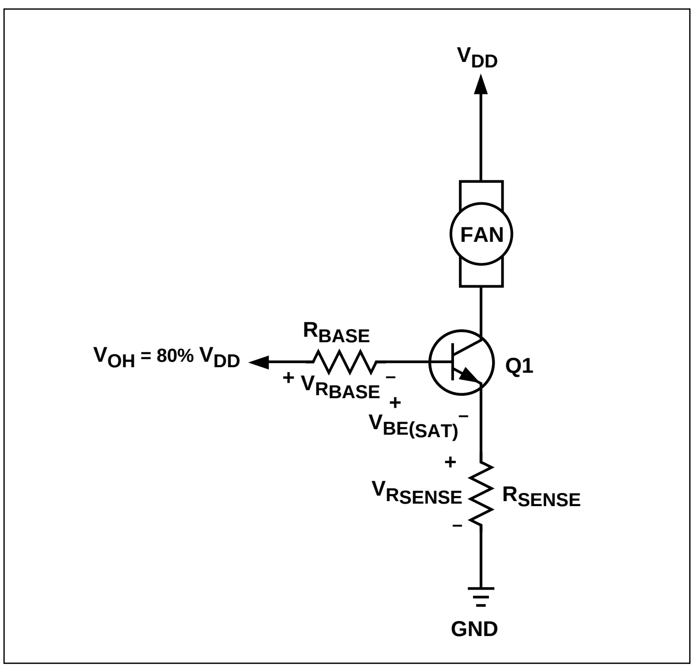


Figure 5. Circuit for Determining R_{BASE}

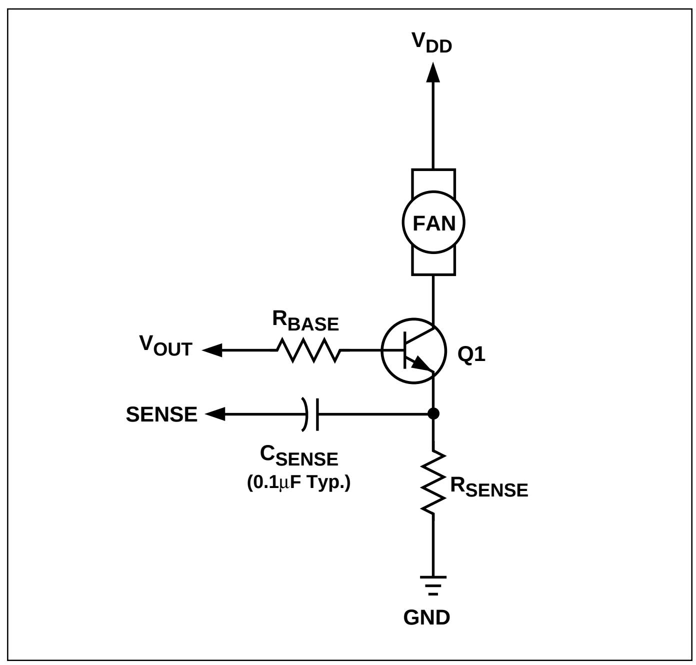


Figure 6. SENSE Network

operates. At certain points, the TC646 may fail to capture a pulse within the 32-cycle Missing Pulse Detector window. When this happens, the 3-cycle Diagnostic Timer will be activated, the V_{OUT} output will be active continuously for three cycles and, if the fan is operating normally, a pulse will be detected. If all is well, the system will return to normal operation. There is no harm in this behavior, but it may be audible to the user as the fan will accelerate briefly when the Diagnostic Timer fires. For this reason, it is recommended that V_{AS} be set no lower than 1.8V.

FanSense™ Network (R_{SENSE} and C_{SENSE})

The network comprised of R_{SENSE} and C_{SENSE} allows the TC646 to detect commutation of the fan motor(FanSense™). This network can be thought of as a differentiator and threshold detector. The function of R_{SENSE} is to convert the fan current into a voltage. C_{SENSE} serves to AC-couple this voltage signal and provide a ground-referenced input to the SENSE pin. Designing a proper SENSE Network is simply a matter of scaling R_{SENSE} to provide the necessary amount of gain, i.e., the current-to-voltage conversion ratio. A 0.1µF ceramic capacitor is recommended for C_{SENSE}. Smaller values require larger sense resistors, and higher value capacitors are bulkier and more expensive. Using a 0.1µF results in reasonable values for R_{SENSE}. Figure 6 illustrates a typical SENSE Network. Figure 7 shows the waveforms observed using a typical SENSE Network.

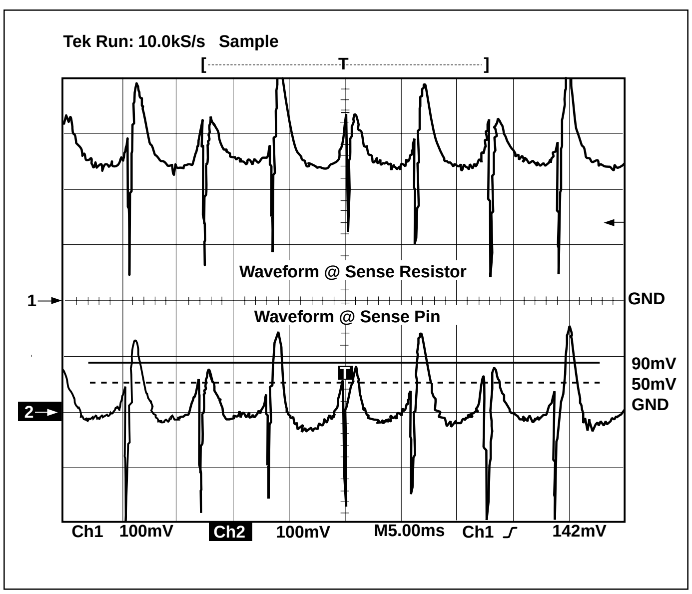


Figure 7. SENSE Waveforms

Table 1 lists the recommended values of R_{SENSE} according to the nominal operating current of the fan. Note that the current draw specified by the fan manufacturer may not be the fan's nominal operating current, but may be a worst-case rating for near-stall conditions. The values in the table refer to actual average operating current. If the fan current falls between two of the values listed, use the higher resistor value. The end result of employing Table 1 is that the signal developed across the sense resistor is approximately 450mV in amplitude.

Table 1. R_{SENSE} vs. Fan Current

Nominal Fan Current (mA)	R_{SENSE} (Ω)
50	9.1
100	4.7
150	3.0
200	2.4
250	2.0
300	1.8
350	1.5
400	1.3
450	1.2
500	1.0

Output Drive Transistor Selection

The TC646 is designed to drive an external transistor for modulating power to the fan. This is shown as “Q1” in Figures 1, 5, 6, 8, 9, and 11. The V_{OUT} pin has a minimum source current of 5mA and a minimum sink current of 1mA. Bipolar transistors or MOSFETs may be used as the power switching element as shown below. When high current gain is needed to drive larger fans, two transistors may be used in a Darlington configuration. These circuit topologies are shown in Figure 8: (a) shows a single NPN transistor used as the switching element; (b) illustrates the Darlington pair; and (c) shows an N-channel MOSFET.

One major advantage of the TC646's PWM control scheme versus linear speed control is that the dissipation in the pass element is kept very low. Generally, low-cost devices in very small packages such as TO-92 or SOT, can be used effectively. For fans with nominal operating currents of no more than 200mA, a single transistor usually suffices. Above 200mA, the Darlington or MOSFET solution is recommended. For the fan sensing function to work correctly, it is imperative that the pass transistor be fully saturated when “on”. The minimum gain (h_{FE}) of the transistor in question must be adequate to fully saturate the transistor when passing the full fan current and being driven within the 5mA I_{OH} of the V_{OUT} output.

Table 2 gives examples of some commonly available transistors. This table is a guide only. There are many transistor types which might work equally as well as those listed. The only critical issues when choosing a device to use as Q1 are: (1) the breakdown voltage, $V_{CE(BR)}$, must be large enough to stand off the highest voltage applied to the fan

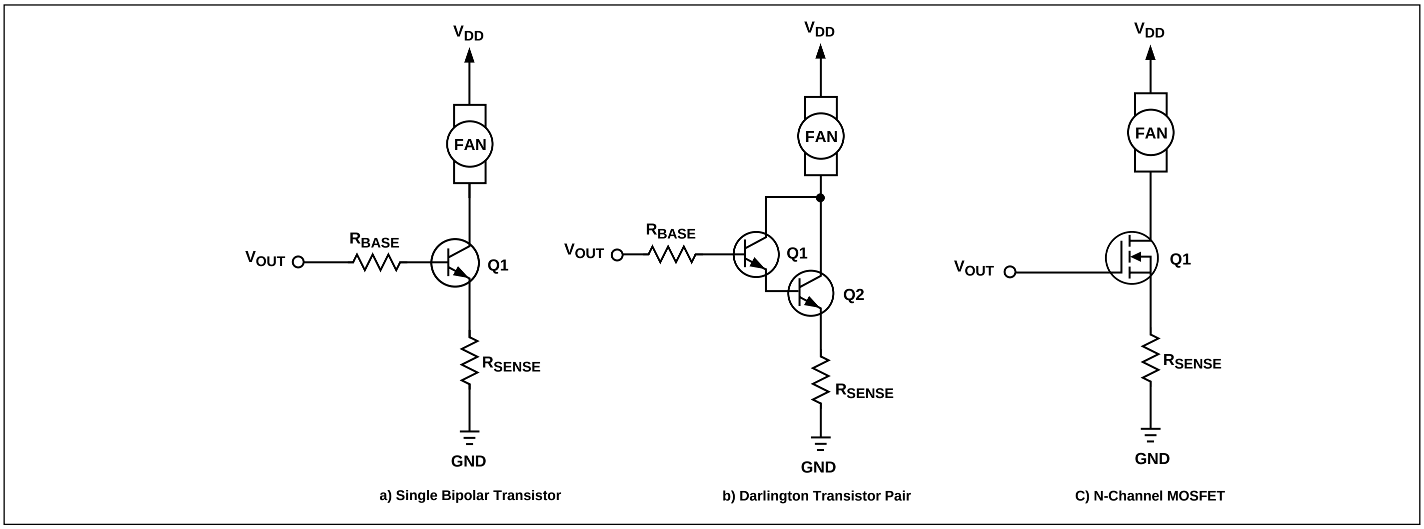


Figure 8. Output Drive Transistor Circuit Topologies

(NOTE: this may be when the fan is off!); (2) the gain (h_{FE}) must be high enough for the device to remain fully saturated while conducting the maximum expected fan current and being driven with no more than 5mA of base/gate drive at maximum temperature; (3) rated fan current draw must be within the transistor's current handling capability; and (4) power dissipation must be kept within the limits of the chosen device.

Table 2. Transistors for Q1

Device	$V_{BE(SAT)}$	MIN h_{FE}	$V_{BR(CEO)}$	I_C	R_{BASE} (Ω)
MPS2222	1.3	100	30	150	800
MPS2222A	1.2	100	40	150	800
2N4400	0.95	50	40	150	820
2N4401	0.95	100	40	150	820
MPS6601	1.2	50	25	500	780
MPS6602	1.2	50	40	500	780

A base-current limiting resistor is required with bipolar transistors. This is shown in Figure 5. The correct value for this resistor can be determined as follows: (see Figure 5).

$$V_{OH} = V_{RSENSE} + V_{BE(SAT)} + V_{RBASE}$$
$$V_{RSENSE} = I_{FAN} \times R_{SENSE}$$
$$V_{RBASE} = R_{BASE} \times I_{BASE}$$
$$I_{BASE} = I_{FAN} / h_{FE}$$

V_{OH} is specified as 80% of V_{DD} in the *Electrical Characteristics* table; $V_{BE(SAT)}$ is given in the transistor data sheet. It is now possible to solve for R_{BASE}.

$$R_{BASE} = \frac{V_{OH} - V_{BE(SAT)} - V_{RSENSE}}{I_{RBASE}}$$

Some applications benefit from the fan being powered from a negative supply to keep motor noise out of the positive supply rails. This can be accomplished as shown in Figure 9, Zener diode D1 offsets the –12V power supply voltage, holding transistor Q1 OFF when V_{OUT} is LOW. When V_{OUT} is HIGH, the voltage at the anode of D1 increases by V_{OH}, causing Q1 to turn ON. Operation is otherwise the same as in the case of fan operation from +12V.

Latch-up Considerations

As with any CMOS IC, the potential exists for latch-up if signals outside the power supply range are applied to the device. This is of particular concern during power-up if the external circuitry, such as the sensor network, V_{AS} divider, or Shutdown circuit, are powered by a supply different from that of the TC646. Care should be taken to ensure that the TC646's V_{DD} supply powers-up *first*. If possible, the networks attached to V_{IN} and V_{AS} should connect to the V_{DD} supply at the same physical location as the IC itself. Even if the IC and any external networks are powered by the same supply, physical separation of the connecting points can result in enough parasitic capacitance and/or inductance in the power supply connections to delay one power supply "routing" versus another.

Power Supply Routing and Bypassing

Noise present on the V_{IN} and V_{AS} inputs may cause erroneous operation of the $\overline{FAULT}$ output. As a result, these inputs should be bypassed with a 0.01µF capacitor mounted as close to the package as possible. This is especially true of V_{IN}, which usually is driven from a high impedance source

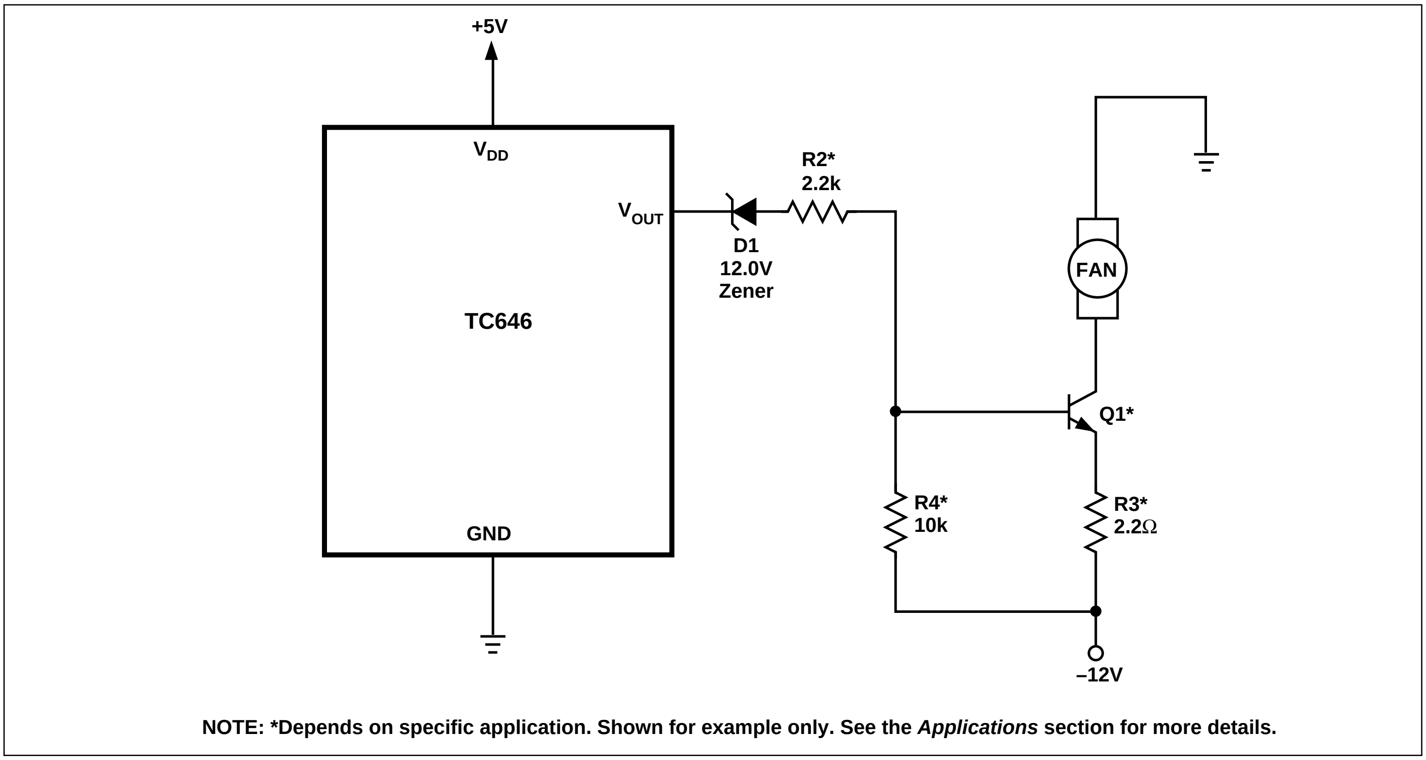


Figure 9. Powering the Fan from a Negative Supply

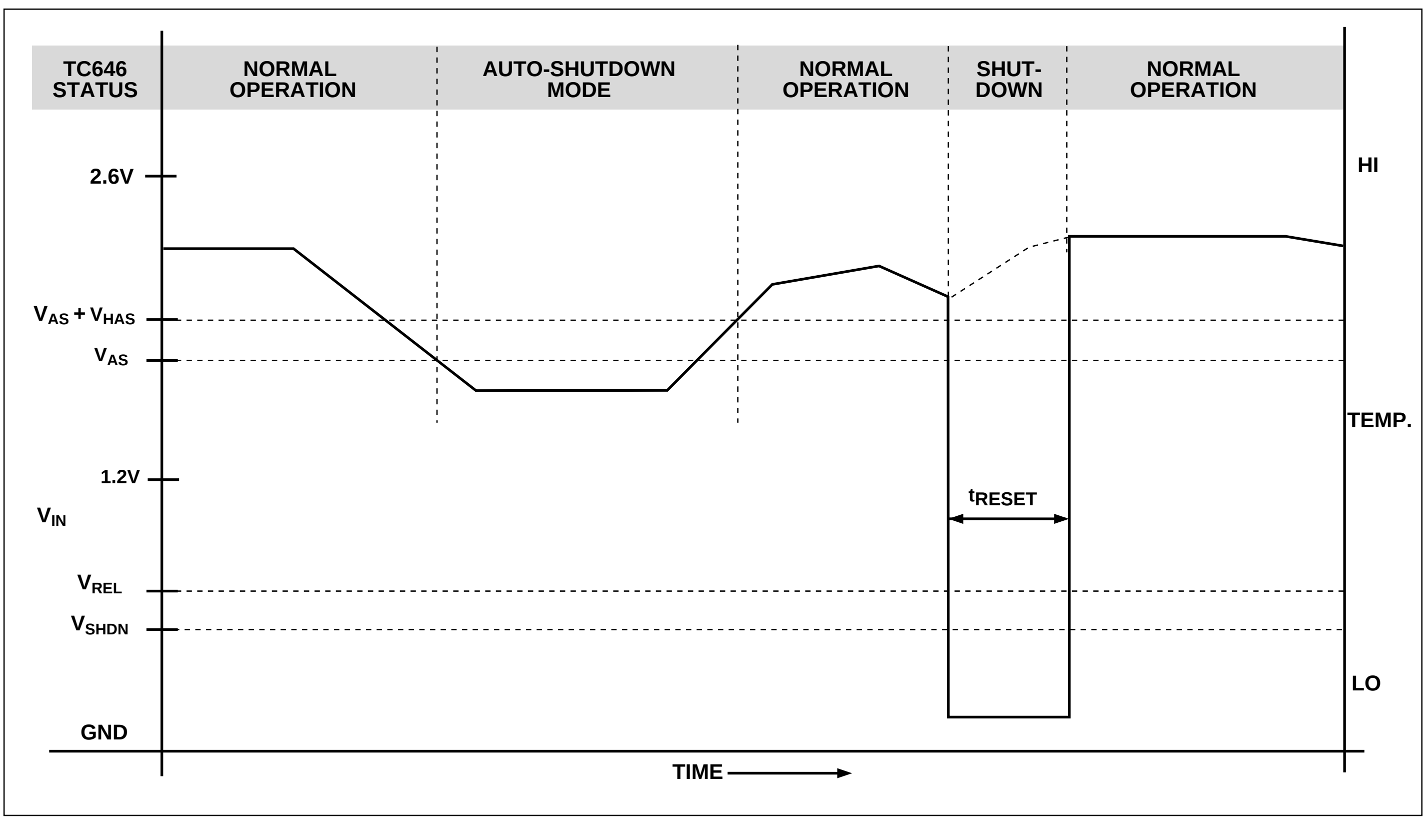


Figure 10. TC646 Nominal Operation

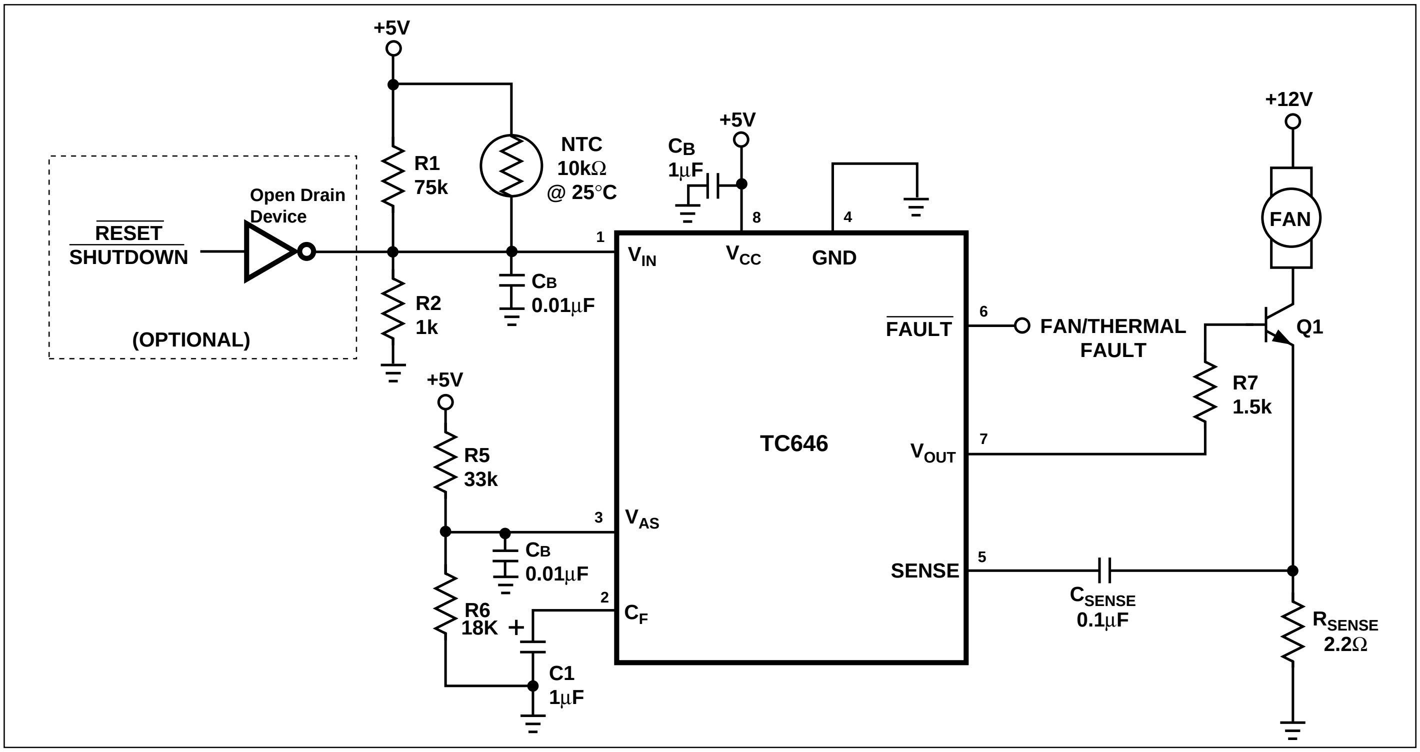


Figure 11. Design Example

(such as a thermistor). In addition, the V_{DD} input should be bypassed with a 1μF capacitor. Grounds should be kept as short as possible. To keep fan noise off the TC646 ground pin, individual ground returns for the TC646 and the low side of the fan current sense resistor should be used.

Design Example (Figure 11)

Step 1. Calculate R1 and R2 based on using an NTC having a resistance of 4.6kΩ at T_{MIN} and 1.1kΩ at T_{MAX}.

R1 = 75kΩ
R2 = 1kΩ

Step 2. Set Auto-Shutdown level

V_{AS} = 1.8V
Limit the divider current to 100μA
R5 = 33k
R6 = 18k

Step 3. Design the output circuit

Maximum fan motor current = 250mA.
Q1 beta is chosen at 100 from which
R7 = 1.5kΩ.

TC646 as a Microcontroller Peripheral (Figure 12)

In a system containing a microcontroller or other host intelligence, the TC646 can be effectively managed as a CPU peripheral. Routine fan control functions can be performed by the TC646 without processor intervention. The micro-controller receives temperature data from one or more points thoughout the system. It calculates a fan operating speed based on an algorithm specifically designed for the application at hand. The processor controls fan speed using complementary port bits I/O_1 through I/O_3. Resistors R1 through R6 (5% tolerance) form a crude 3-bit DAC that translates this 3-bit code from the processor's outputs into a 1.6V to 2.6V DC control signal. (A monolithic DAC or digital pot may be used instead of the circuit shown.)

With V_{AS} set at 1.8V, the TC646 enters Auto-Shutdown when the processor's output code is 000[B]. Output codes 001[B] to 111[B] operate the fan from roughly 40% to 100% of full speed. An open drain output from the processor (I/O_0) can be used to reset the TC646 following detection of a fault condition. The $\overline{\text{FAULT}}$ output can be connected to the processor's interrupt input, or to another I/O pin for polled

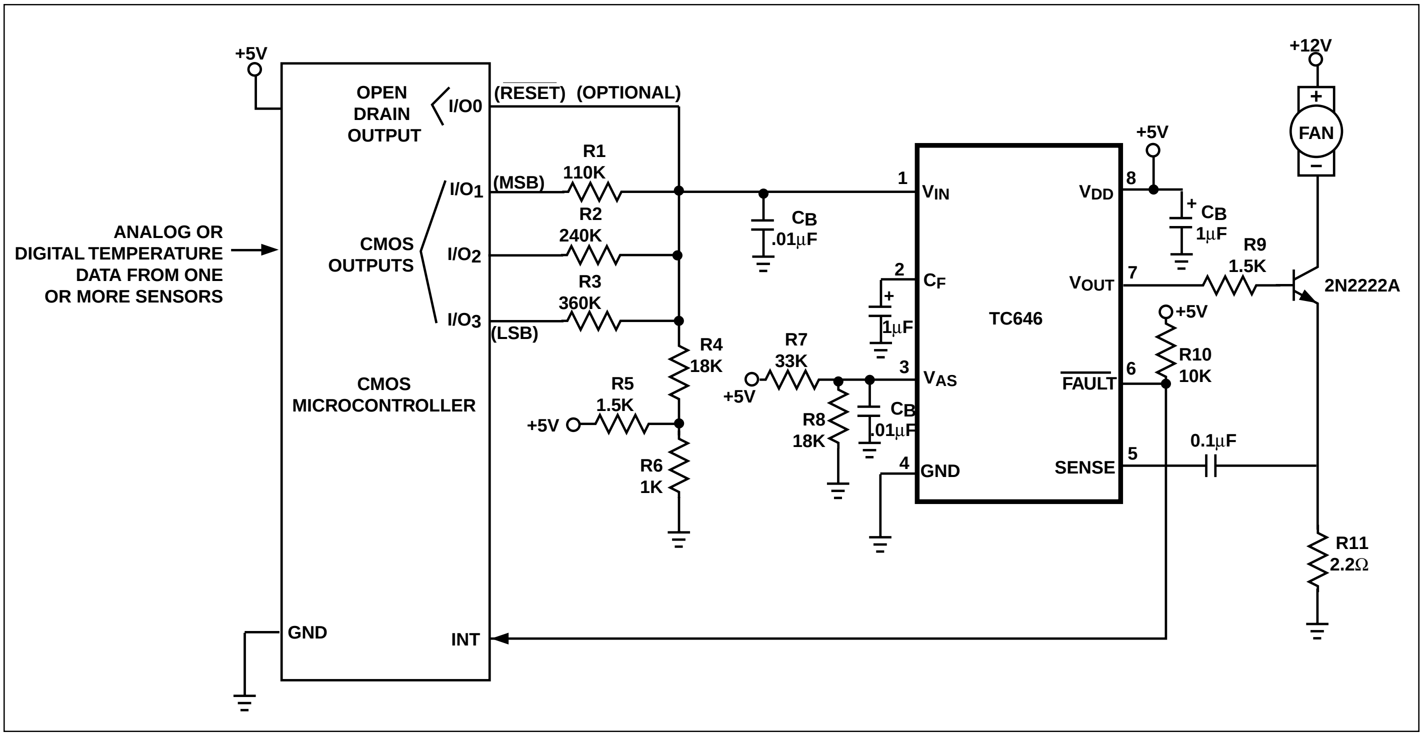


Figure 12.

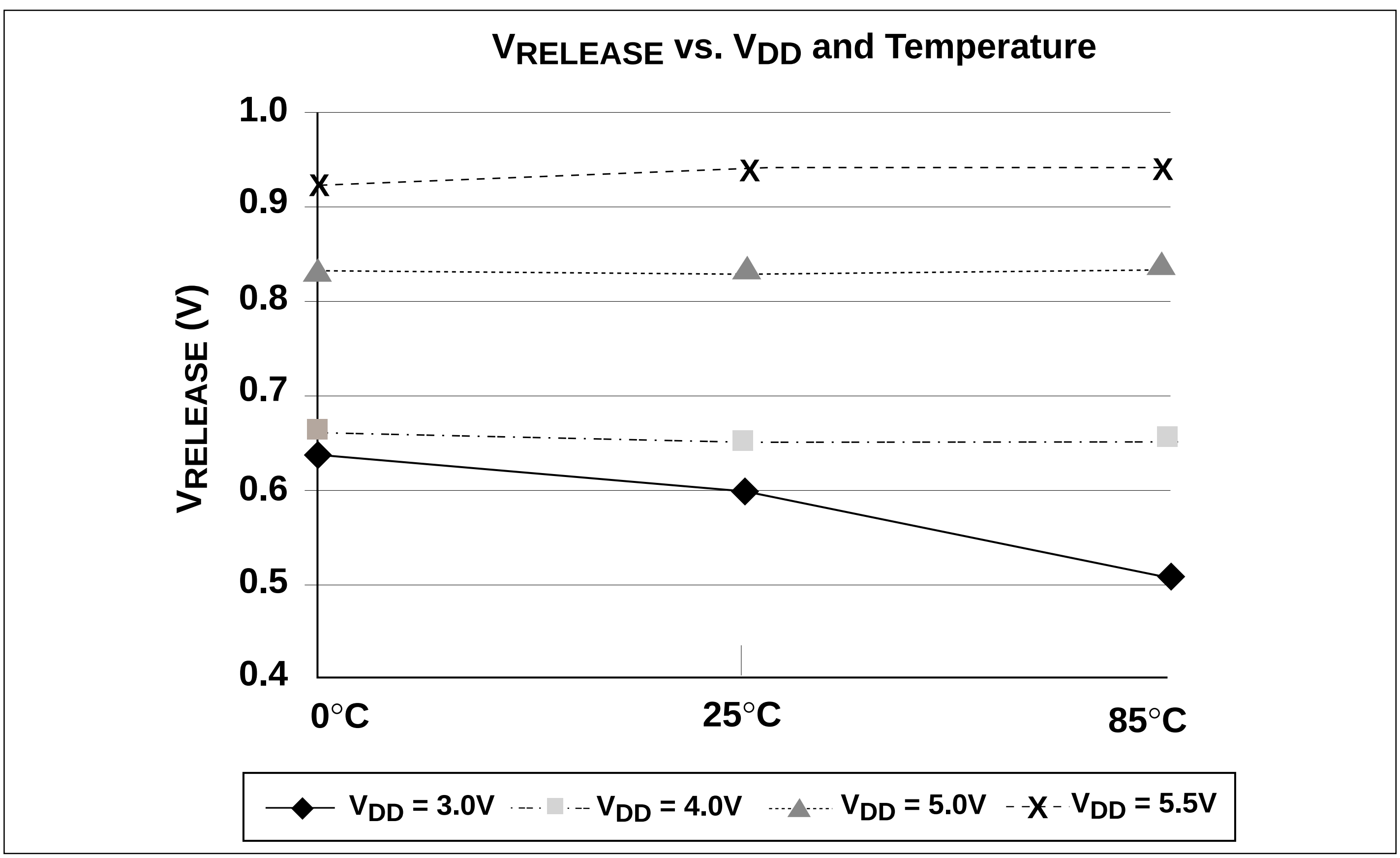
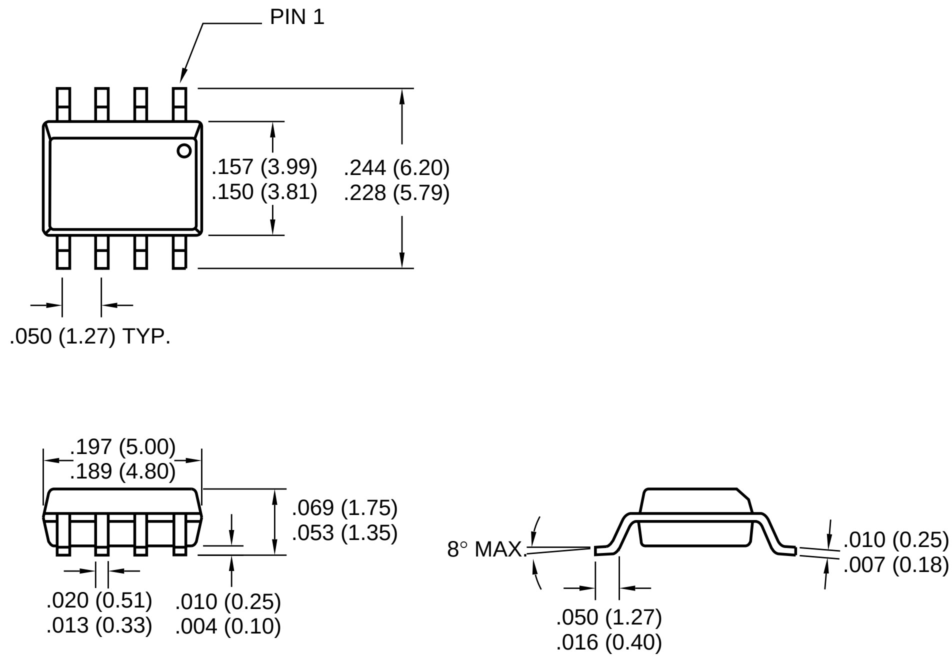


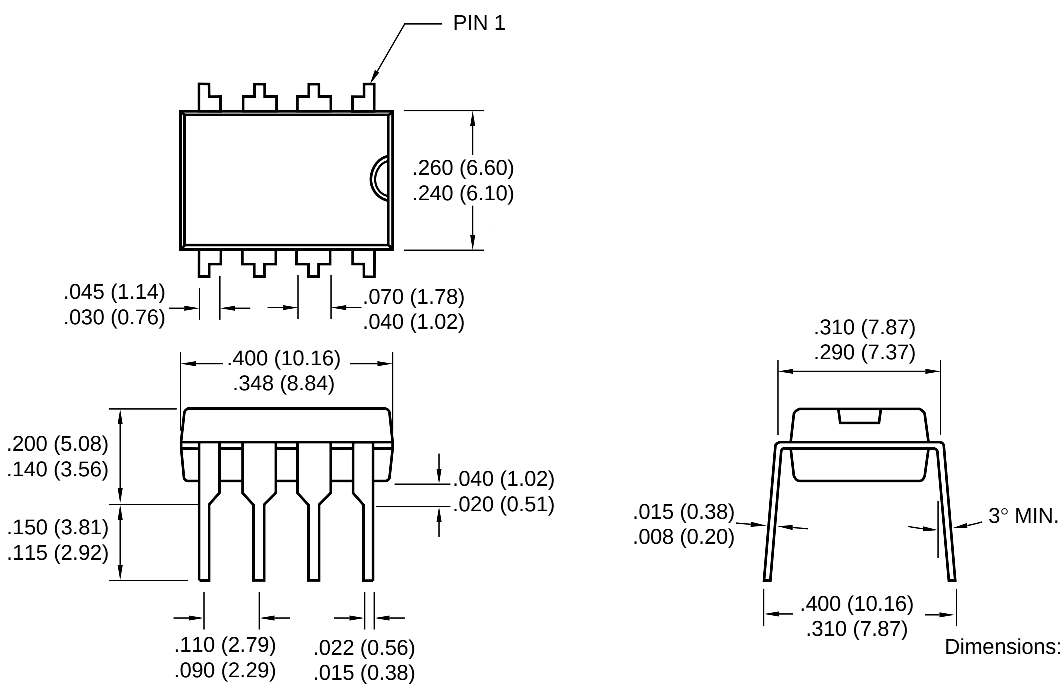
Figure 13.

PACKAGE DIMENSIONS (CON'T.)

8-Pin SOIC



8-Pin Plastic DIP



Dimensions: inches (mm)

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